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(54) Polarization illumination apparatus and projector using the apparatus

Vorrichtung zur Beleuchtung mit polarisiertem Licht und Projektor, der diese Vorrichtung verwendet

Dispositif d'illumination polarisée et projecteur utilisant ce dispositif

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Description

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a polarization illumination apparatus and a projector having the polarization illumination apparatus.

Related Background Art

Fig. 1 is a view showing an arrangement of main part of a conventional projector using a polarization illumination apparatus. The projector includes a light source 1, a reflection mirror 2, a polarization beam splitter 6, a polarization beam splitting film 20, a liquid crystal light valve 7, and a quarter-wave optical phase plate 13. In Fig. 1, the end portions of two polarization beam splitting films 20_1 and 20_2 are in contact with each other to form an angle of about 90° therebetween. Random light Ao emitted from the light source 1 is converted into substantially parallel light (i.e., light substantially parallel to the optical axis) by the reflection mirror 2, and the parallel light is incident on the first polarization beam splitting film 20_1. In this case, p-polarized light Ap_1 is transmitted through the film 20_1, and s-polarized light As is reflected by the film 20_1. The S-polarized light As is further reflected by the second polarization beam splitting film 20_2 arranged along the optical path, and is then converted into circularly polarized light Ar via the quarter-wave optical phase plate 13 whose optical axis is set in a desired direction. The circularly polarized light Ar is transmitted through the quarter-wave optical phase plate 13 again via the light source 1 and the reflection mirror 2, and is converted into light Ap_2 including p-polarized light. The light Ap_2 is transmitted through the polarization beam splitting film 20_1, and is then incident on the liquid crystal light valve 7.

In this projector, the two polarized light components, i.e., the p-polarized light Ap and the s-polarized light split by the polarization beam splitting film 20_1 or 20_2 are converted to polarized light components having the same direction of polarization so as to illuminate the liquid crystal light valve 7. With this projector, light utilization efficiency can be improved as compared to a projector using no polarization illumination apparatus.

However, since the conventional projector uses the optical phase plate, the light amount is undesirably decreased due to absorption or reflection when light is transmitted through the plate. A conventional plastic op[illegible] emerges therefrom [illegible] through the optical phase plate a total of three times, the light amount is considerably decreased.

Document US-A-5 042 921 discloses a polarization illumination apparatus according to the preamble of claim 1, which also uses a phase plate for changing the polarization state.

Furthermore, document WO-A-92 01969 which constitutes prior art within the meaning of Art. 54(3) EPC discloses a polarization illumination apparatus for a liquid crystal display, which does not require any optical phase plates. Therein, the polarization state of the light component returned from the polarization beam splitter is depolarized by deflecting it at a rough suface provided on a glass body of the light bulb constituting the light source after being reflected at a spherical or elliptic mirror.

It is an object of the present invention to provide a polarization illumination apparatus having a high light utilization efficiency and which does not require an optical phase plate.

This object is achieved by a polarization illumination apparatus according to claim 1.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view showing an arrangement of a conventional projector;

Fig. 2 is a view for explaining an operation of an embodiment of a polarization illumination apparatus according to the present invention;

Fig. 3 is a view for explaining the principle of the operation of the polarization illumination apparatus of the present invention;

Fig. 4 is a view for explaining the principle of the operation of the polarization illumination apparatus of the present invention;

Fig. 5 is a view showing another embodiment of a polarization illumination apparatus according to the present invention;

Figs. 6A to 6C are views showing other embodiments of a polarization illumination apparatus according to the present invention;

Fig. 7 is a view showing still another embodiment of a polarization illumination apparatus according to the present invention;

Figs. 8A and 8B are views showing other embodiments of a polarization illumination apparatus according to the present invention;

Fig. 9 is a view showing still another embodiment of a polarization illumination apparatus according to the present invention;

Figs. 10A and 10B are views showing other embodiments of a polarization illumination apparatus according to the present invention;

Fig. 11 is a view showing still another embodiment [illegible] view showing [illegible] of a polarization illumination apparatus according to the present invention; and

Fig. 13 is a view showing an embodiment of a projector according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 2 shows an embodiment of the present invention.

In Fig. 2, an apparatus of this embodiment includes a metal halide lamp 1 serving as a light source, a reflection mirror 2 serving as a light condensing means, and having a shape of a paraboloid of revolution, a polarization beam splitting (to be abbreviated as PBS hereinafter) film 20, rectangular prisms 21a and 21b, and a plane reflection mirror 22. A polarization beam splitting means is constituted by the PBS film 20, the rectangular prisms 21a and 21b, and the plane reflection mirror 22. The light source 1 is arranged at a focal point position 2c of the parabolic mirror 2, thus obtaining a substantially parallel beam. The substantially parallel beam is split into two linearly polarized light components by a polarization beam splitter. One polarized light component is perpendicularly reflected by the plane reflection mirror 22 arranged on one outgoing face of the polarization beam splitter, and is converted into light (to be referred to as return light hereinafter) returning to the parabolic mirror 2.

A process for obtaining linearly polarized light from substantially parallel light as indefinitely polarized light will be described in detail below.

A ray 1_{10} emitted from the center of the light source arranged at the focal point 2c of the parabolic mirror 2 is converted into a parallel ray 1_{11} (i.e., a ray parallel to the optical axis) by by the parabolic mirror 2, and the parallel ray 1_{11} is incident on the prism 21b. At this time, the ray 1_{11} is natural light whose direction of polarization is indefinite. The ray 1_{11} which has reached the PBS film is subjected to the polarization beam splitting effect, and is split into a pair of linearly polarized light components 1_{11P} and 1_{11S} having different directions of polarization. The light component 1_{11P} is normally called p-polarized light since its direction of polarization, i.e., the vibration direction of polarization is parallel to the plane of drawing. The light component 1_{11P} is transmitted through the PBS film 20, propagates through the prism 21a, and emerges as polarized illumination light from the outgoing face at the side opposite to the incident face of the ray 1_{11}.

On the other hand, the light component 1_{11S} is normally called s-polarized light since its vibration direction of polarization is perpendicular to the plane of drawing. The light component 1_{11s} is perpendicularly reflected by the PBS film 20, and propagates through the prism 21b toward the plane reflection mirror 22. Since the plane [illegible] ...ized light 1_{11S} changes its propagation direction through 180°, and then propagates toward the PBS film 20 again. Since the light component 1_{11S} is s-polarized light, it is reflected by the PBS film 20 again, and returns as return light $1_{11S}'$ along the same optical path (Fig. 2 illustrates distinguishing optical paths before and after reflection for the sake of easy understanding) in the opposite direction. Since the return light $1_{11S}'$ is parallel light, it is reflected at a point 2a on the parabolic mirror 2, and returns to the light source 1 located at the focal point 2c.

The return light $1_{11S}'$ propagates toward the parabolic mirror 2 again as if it were light emitted from the light source 1, and is reflected at a point 2b to be converted into a parallel ray 1_{12}. The parallel ray 1_{12} is re-incident on the prism 21b. The polarization state of the ray 1_{12} is considerably disturbed for a reason to be described later, and the ray 1_{12} is split into a pair of linearly polarized light components 1_{12P} and 1_{12S} by the PBS film 20. Since the light component 1_{12P} is p-polarized light as in the light component 1_{11P}, it is transmitted through the PBS film, propagates through the prism 21a, and emerges from the prism as polarized illumination light. On the other hand, the light component 1_{12S} behaves as return light which returns to the light source via the plane reflection mirror 22 as in the light component 1_{11S}. Upon repetition of the above-mentioned process, all natural light components can be converted into polarized light components in principle.

A change in polarization state of linearly polarized light after it is split by the polarization beam splitting means and returns to the light condensing means will be described below with reference to Figs. 3 and 4.

In Fig. 3, return light 1_{21} is reflected at the two points 2a and 2b on the parabolic mirror 2, and emerges as rays 1_{22} and 1_{23}. In Fig. 3, 2c represents the focal point of the parabolic mirror 2, Ga and Gb represent the tangent planes of the points 2a and 2b, and Ha and Hb represent the normals to the points 2a and 2b.

The vibration direction (polarizing direction) of the return light 1_{21} is inclined by α_i with respect to the plane of drawing. α_i is called an azimuth, and assumes a positive value when the vibration direction rotates clockwise with respect to the propagation direction of light. Fig. 4 is a view for explaining the azimuth α_i when the opening of the reflection mirror 2 shown in Fig. 2 is viewed from the direction of the PBS film. In Fig. 4, a plane including m_1 is parallel to the plane of drawing of Fig. 2, and a plane including m_2 is perpendicular to the plane of drawing of Fig. 2. In Fig. 4, a double-headed arrow indicates the vibration direction of the return light 1_{21}. Fig. 3 is a sectional view taken along m_3 rotated from this vibration direction by α_i.

As described above, the return light 1_{21} is linearly polarized light. When linearly polarized light is reflected by a given boundary surface (e.g., reflected at the point [illegible]

for

$$\sin x = \sin\theta_i / n \qquad (2)$$

where α_i is the azimuth (an angle defined between the vibration direction and the plane m_3, as shown in Fig. 4, will be referred to as an azimuth hereinafter) upon incidence of the light 1_{21}, α_r is the azimuth upon reflection of the light 1_{21}, n is the refractive index of the parabolic mirror 2, and θ_i is the incident angle with respect to the planes Ga and Gb ("Principle of Optics, Tokai Univ. Press").

The refractive index n assumes a real number when the parabolic mirror 2 is a dielectric, and a complex number when it is a conductor. The way of the change in polarization state after reflection depends on the refractive index n.

A case will be described below wherein the parabolic mirror 2 is a dielectric, i.e., the refractive index n assumes a real number. n is the refractive index of a medium of the parabolic mirror 2 when viewed from a medium (air in Fig. 3) where the light 1_{21} propagates, and satisfies n > 1. For this reason, x is also expressed by a real number from formula (2), and α_r is expressed by a real number, too, from formula (1). Therefore, from formula (1), the vibration direction rotates in a direction to separate from the plane m_3 ("Principle of Optics", p. 71). As can be understood from formulas (1) and (2), α_r at that time varies depending on θ_i. Also, as can be seen from Fig. 3, since θ_i satisfies $0 < \theta_i < \theta_{imax}$ (θ_{imax} is the angle when the point 2a is located at the end portion of the parabolic mirror 2), and assumes every possible value, the azimuth of the light 1_{21} also assumes every possible value.

In reflection at the point 2b, the incident angle assumes every possible value while satisfying:

$$\theta_{ib} = \pi/2 - \theta_{ia} \qquad (3)$$

Consequently, the azimuth of the light 1_{23} can assume every possible value. Therefore, the vibration directions of outgoing light components including the light 1_{23} propagating parallel to the plane of drawing of Fig. 3 are various, and the outgoing light components are in a non-polarized state as a whole. Since the mirror 2 has a shape of a paraboloid of revolution, the azimuth α_i of the light 1_{21} naturally assumes every possible value within a range of $-\pi/2 < \alpha_i < \pi/2$. From this viewpoint, the polarization state of the outgoing light from the parabolic mirror 2 is disturbed.

[illegible]

On the other hand, when the parabolic mirror 2 is a conductor, i.e., when the refractive index n assumes a complex number, the case is different. Since n assumes a complex number, x also assumes a complex number from formula (2). Therefore, since α_r assumes a complex number from formula (1), a phase shift occurs, and the reflected light 1_{22} is generally converted to elliptically polarized light ("Principle of Optics", p. 911).

One of necessary conditions that the light 1_{22} converted into elliptically polarized light is converted into linearly polarized light again upon reflection at the next reflection point 2b is given by:

$$\theta_{ia} = \theta_{ra} = \theta_{ib} \qquad (4)$$

where θ_{ra} is the reflection angle at the point 2a. This is because when linearly polarized light which is incident on a given interface at an incident angle θ_i is reflected at a reflection angle θ_r ($= \theta_1$), and is converted into elliptically polarized light to have a phase difference δ, elliptically polarized light having a phase difference $-\delta$ which is incident on a similar interface at the incident angle θ_r ($= \theta_i$) is reflected onto the interface, and is converted into linearly polarized light according to the principle of retrogradation of light. That is, in order that linearly polarized light and elliptically polarized light having a phase difference δ therewith retrograde and substitute each other upon reflection, they must satisfy at least formula (4).

Now, since $\theta_{ia} + \theta_{ib} = \pi/2$, formula (4) is not satisfied in general. Even though formula (4) is satisfied, the light 1_{23} cannot be converted into linearly polarized light having the same vibration direction as that of the light 1_{21} unless a phase difference of $\pi/2$ is generated at each of the reflection points 2a and 2b of the parabolic mirror 2 shown in Fig. 3. Therefore, since it can be considered that the light 1_{23} can never be linearly polarized light, it is obvious that the light 1_{23} is split into a pair of linearly polarized light components by the PBS film 20 shown in Fig. 2.

When the azimuth α_i = O or $\pi/2$, the vibration directions of the light 1_{21} and the light 1_{23} coincide with each other. In other words, the vibration direction is not rotated even via the parabolic mirror 2, and the light is always incident on the PBS film as s-polarized film. Therefore, the light reciprocally propagates between the plane reflection mirror 22 and the parabolic mirror 2 via the PBS film 20, and does not serve as illumination light.

Upon reflection on a dielectric reflection surface, the rotation (change in α) of the vibration direction is small, and the number of p-polarized light components of the light 1_{23} with respect to the PBS film 20 may become smaller than the number of s-polarized light component [illegible]

[illegible] converted into elliptically polarized light [illegible] linearly polarized light. As a result, the number of p-polarized light components with respect to the PBS film 20 may become smaller than the number of s-polarized

light components. In such cases, in order to positively disturb the vibration direction of the return light 1_{21}, the light source lamp preferably has a diffusion surface.

The diffusion surface is normally considered as a state wherein a large number of very small prisms cover a surface. Since a prism normally has a very small capacity for changing the vibration direction of polarized light, the diffusion surface also has a very small capacity for changing the vibration direction of polarized light. However, the diffusion surface can change the propagation direction of light. For example, as shown in Fig. 5, polarized light 1_{22} having a given vibration direction is diffused by the surface of the light source 1, and is split into polarized light components 1_{221}, 1_{222}, 1_{223}, and 1_{224}. When these light components are incident on various points on the parabolic mirror 2 at various incident angles and are reflected at various azimuths, different polarized light components 1_{231}, 1_{232}, and 1_{233} can be obtained in addition to polarized light 1_{23}, thus further disturbing the vibration direction of polarized light.

The reason why the diffusion surface is arranged on or near the lamp surface is that light diffused by the diffusion surface is caused to behave as if it were emitted from the light source 1. If the diffusion surface is arranged at another place, substantially parallel light cannot be obtained by the light condensing means.

The PBS film of this embodiment is normally formed of a dielectric multi-layered film, and is adhered sandwiching between the two rectangular prisms 21a and 21b, thus constituting a so-called polarization beam splitter. The PBS film is designed to split light having an incident angle of 45° into p- and s-polarized light components. A polarization beam splitter corresponding to another incident angle can be manufactured as long as the incident angle is not considerably shifted from 45°

As the plane reflection mirror 22, a mirror prepared by depositing aluminum on a flat glass plate is normally used. In order to increase the reflectance, a coating for increasing the reflectance may be formed on the mirror. The mirror 22 must be arranged, so that its reflection surface extends perpendicular to the propagation direction of s-polarized light split splitted by the polarization beam splitter.

The parabolic mirror 2 is preferably formed by a cold mirror to prevent a temperature rise of an object to be illuminated since the light source 1 emits a large amount of infrared light. In this embodiment, the reflection mirror having a shape of a paraboloid of revolution, whose sectional shape can be normally expressed by $y = ax^2$, is used. Alternatively, a mirror having a substantially parabolic shape, whose sectional shape can be ex- [illegible] correspondence with the light emission characteristics of the light source

In the polarization illumination apparatus of the present invention, since return light propagating toward the reflection mirror of the light condensing means is not transmitted through a quarter-wave optical phase plate unlike in the prior art, it remains linearly polarized light. Therefore, the return light can be split into p- and s-polarized light components by the PBS film 20 again owing to the following two effects:

1. rotation of the vibration direction of linearly polarized light upon reflection; and
2. modulation from linearly polarized light into elliptically polarized light due to a phase shift upon reflection when the reflection mirror is formed of a conductor.

Other embodiments of a polarization illumination apparatus according to the present invention will be described below.

In an embodiment shown in Fig. 6A, p-polarized light split by the polarization beam splitter formed by the prisms 21a and 21b and the PBS film 20 is caused to return to the light condensing means, i.e., the parabolic mirror 2 by the reflection mirror 22 unlike in the first embodiment wherein s-polarized light returns to the light condensing means.

In embodiments shown in Figs. 6B and 6C, the PBS film 20 is adhered between triangular prisms 21c and 21d each having a right-angled triangular shape. In Fig. 6B, light incident on the prism 21c via the light condensing means (parabolic mirror 2) reaches the PBS film 20 or a total reflection surface c. A light component which has reached the PBS film 20 is split into s- and p-polarized light components by the PBS film 20. The p-polarized light component emerges from the outgoing face of the prism 21d, and the s-polarized light component is reflected by the PBS film and reaches the total reflection surface c. The s-polarized light component is reflected by the total reflection surface c to be converted into return light, which returns to the light condensing means.

On the other hand, of light components incident on the prism 21c, a light component which has reached the total reflection surface c is reflected by the surface c, and propagates toward the PBS film 20. The light component is split into s- and p-polarized light components by the PBS film 20, and the s-polarized light component becomes return light, which returns to the light condensing means. The p-polarized light component is reflected by a total reflection surface d, and emerges from the outgoing face.

In Fig. 6C, light incident on the prism 21c via the light condensing means (parabolic mirror 2) reaches the PBS film 20 or the total reflection surface c. The light which has reached the PBS film 20 is split into s- and p- [illegible] surface d and then emerges from the outgoing face. The s-polarized light component is reflected by the PBS film and reaches the total reflection surface c. The s-polarized light component is further reflected by the surface c, and becomes return light, which returns to the

light condensing means.

On the other hand, of light components incident on the prism 21c, a light component which has reached the total reflection surface c is reflected by the surface c, and propagates toward the PBS film 20. The light component is split into s- and p-polarized light components by the PBS film. The s-polarized light component is reflected, and becomes return light, which returns to the light condensing means. The p-polarized light component emerges from the outgoing face of the prism 21d.

In an embodiment shown in Fig. 7, three triangular prisms 21e, 21f, and 21g each having a right-angled triangular section are combined, as shown in Fig. 7, and PBS films 20a and 20b are arranged on the boundary surfaces of these prisms.

Light incident through the parabolic mirror 2 is transmitted through the prism 21e, and is split into p- and s-polarized light components by the PBS film 20a or 20b. The p-polarized light component directly emerges from the outgoing face. The s-polarized light component is reflected by the other PBS film, and becomes return light, which returns to the parabolic mirror 2.

In the embodiments shown in Figs. 6B, 6C, and 7, since a portion formed by the prisms has a volume about half that of the embodiments shown in Figs. 2 and 6A, a compact, low-cost polarization illumination apparatus can be realized.

In embodiments shown in Figs. 8A and 8B, a glass plate layer 23 is used in place of the prisms and the PBS film used in the above-mentioned embodiments. Since a glass plate has polarization beam splitting characteristics as long as a Brewster angle θ_i is maintained, a polarization beam splitting means can be constituted by stacking a plurality of glass plates without forming a PBS film. As the number of glass plates to be stacked is increased, the polarization beam splitting characteristics can be improved but the transmittance may be decreased. Thus, a PBS film formed of a dielectric multilayered film may be arranged between the glass plates, as needed. The plane reflection mirror 22 is arranged perpendicularly to light reflected by the glass plate layer so that light reflected by the glass plate layer 23 returns along the same optical path.

Fig. 8B shows an application illustration of Fig. 8A. In Fig. 8B, two sets of the glass plate layers 23 and the plane reflection mirrors 22 are arranged to have the optical axis of the light condensing means as an axis of symmetry.

In the embodiments shown in Figs. 8A and 8B, a lightweight, low-cost apparatus can be realized as compared to the embodiments using the prisms. In the em- [illegible] 8A, the apparatus can be rendered compact.

In the embodiments shown in Figs. 6A to 8B, the polarization state of the return light returning to the light condensing means is disturbed since the light is reflected by the parabolic mirror 2 as the light condensing means, and the light emerges from the light condensing means again. In these embodiments, the light source 1 may also have a diffusion surface.

Fig. 9 shows still another embodiment, which has two sets of light sources and light condensing means. Of light emerging from one light condensing means, s-polarized light reflected by the PBS film 20 propagates toward the other light condensing means. This embodiment also comprises a prism 21h having a reflection surface 22 for directing p-polarized light components, transmitted through the PBS film 20, of light components from the two light condensing means in the same direction.

Figs. 10A and 10B show other embodiments, each of which has two sets of light sources, light condensing means, and PBS films. In Fig. 10A, of light emerging from one light condensing means, s-polarized light reflected by one PBS film propagates toward the other light condensing means via the other PBS film, and of light components emerging from the two light condensing means, p-polarized light components transmitted through the PBS films emerge in the same direction.

In Fig. 10B, of light emerging from one light condensing means, p-polarized light transmitted through one PBS film propagates toward the other light condensing means through the other PBS film, and of light components emerging from the two light condensing means, s-polarized light components reflected by the PBS films emerge in the same direction.

In the embodiments shown in Figs. 9 to 10B, since the two light sources are used, the light amount can be greatly increased. Normally, in order to increase the light amount, the output of the light source may be simply increased. However, when the output of the light source is increased, the size of the light-emitting portion of the light source is inevitably increased, and parallelness of light via the light condensing means is impaired. When an object to be illuminated having angle dependency such as a liquid crystal light valve is illuminated, it is a necessary condition that illumination light be approximate to parallel light. For this reason, it is very preferable if the light amount can be increased without increasing the size of the light-emitting portion like in the embodiments shown in Figs. 9 to 10B.

Fig. 11 shows still another embodiment. In this embodiment, a section constituted by prisms in the embodiment shown in Fig. 6B or 7 is rendered compact, and a plurality of sections are aligned on the same plane. In Fig. 11, these sections include PBS films 20 and PBS films or reflection films 20'.

An embodiment for minimizing a decrease in paral- [illegible] lamp bulb portion [illegible] haves to have the surface of the lamp bulb portion as a secondary light source, this is equivalent to an increase in diameter of the lamp, and parallelness is decreased. Therefore, in order to minimize a decrease in parallel-

ness, a light source, which does not scatter light by the surface of the lamp bulb portion, can be used. A xenon lamp can form a smooth bulb portion as compared to that of a metal halide lamp. For this reason, the xenon lamp allows easy formation of a lamp, in which light incident on the lamp bulb portion is not easily scattered.

Fig. 12 shows an embodiment for preventing return light from being absorbed when it passes through the lamp bulb portion and the light-emitting portion, and from becoming loss light.

This embodiment is substantially the same as the embodiment shown in Fig. 6B, except that the prism 21c is replaced with a prism 21c'.

In this embodiment, a rectangular prism 21d having a triangular prism shape whose section has a right-angled triangular shape, and an acute-angle (close to a right angle) prism 21c' (a section including a broken line in Fig. 12 has a right-angled triangular shape) having a surface which has the same shape and the same area as those of surfaces sandwiching the right angle of the rectangular prism 21d are adhered to each other, as shown in Fig. 12. The PBS film 20 is provided between the adhered surfaces. Note that the PBS film 20 as a multi-layered film may be provided to one of the rectangular prism 21d and the acute-angle prism 21c, and thereafter, these prisms may he adhered to each other, or the PBS film 20 may be provided to both the prisms, and thereafter, the prisms may be adhered to each other. In addition, aluminum may be deposited on total reflection surfaces c and d, as needed.

In Fig. 12, of parallel light 1_{11} converted through the parabolic mirror 2, p-polarized light 1_{11P} is transmitted through the PBS film 20, and emerges from the rectangular prism 21d. On the other hand, s-polarized light 1_{11S} reflected by the PBS film 20 is reflected by the total reflection surface c, and becomes return light $1_{11S}'$. Since the PBS film 20 and the total reflection surface c do not form a right angle, the return light $1_{11S}'$ is not parallel to the parallel light 1_{11}, and propagates toward the parabolic mirror 2. The return light $1_{11S}'$ propagates toward the light source 1 arranged at the focal point position of the parabolic mirror 2 via the parabolic mirror 2. In this case, since the principle of disturbing the vibration direction of polarized light upon reflection on the parabolic mirror 2 is the same as that in the first embodiment, a detailed description thereof will be omitted. As described above, since the return light $1_{11S}'$ is not parallel to the parallel light 1_{11}, it does not accurately propagate toward the light source 1 even after it is reflected by the parabolic mirror 2, and passes by the light source 1 while avoiding the light-emitting portion. The return light [illegible] [illegible] on the prism 21c' [illegible] mirror 2, and is split into light components 1_{12P} and 1_{12S} by the PBS film 20 again. Since the essence of this embodiment is that at least some of light components returning to the parabolic mirror 2 and the light source 1 via the PBS film 20 do not pass through the light-emitting portion of the light source, the total reflection surface c may form 45° with the parallel light 1_{11}, and the PBS film 20 may form an angle other than 45° with the parallel light 1_{11}. One or both of the PBS film 20 and the total reflection film c may have a curvature, so that the optical path of the return light does not pass through the light-emitting portion. In this case, it is to be noted that the incident angle of the light 1_{12} which is not parallel light should not considerably exceed an allowable angle of the PBS film 20 having angle dependency.

This embodiment can be considered as an application of Fig. 6B. However, in other embodiments, the same effect as in this embodiment can be provided by changing the inclination of the plane reflection mirror or the total reflection surface for returning light toward the light source or by giving a curvature thereto. When a curvature is given, the reflection mirror or surface is preferably formed as a concave mirror having converging characteristics since light does not diverge and become loss light.

Fig. 13 shows an embodiment of a projector according to the present invention. A polarization illumination apparatus 24 adopts one of the embodiments described above.

When polarized light from the polarization illumination apparatus 24 is transmitted through a liquid crystal light valve 7, the light is converted into a beam including image information, and only image light is transmitted through a polarization plate 8. The image light is projected onto a screen (not shown) via a projection lens 10.

A color separation optical system for separating white light into color light components, i.e., red, blue, and green light components may be arranged between the polarization illumination apparatus 24 and the liquid crystal light valve 7, a color mixing optical system may be arranged between the liquid crystal light valve 7 and the projection light 10, and liquid crystal light valves may be arranged in correspondence with optical paths of respective color components. Some or all components of the color separation optical system may be arranged between the light condensing means and the polarization beam splitting means of the polarization illumination apparatus. In this case, a plurality of polarization beam splitting means are required. In general, since the PBS film has wavelength dependency, a better design which achieves an increase in efficiency and satisfactory color reproduction can be attained if PBS films suitable for color-separated light components are prepared.

A plurality of image light beams may be projected by a plurality of projection lenses without using the color [illegible] apparatuses may be [illegible] aration optical system so as to illuminate corresponding liquid crystal light valves.

In the embodiment shown in Fig. 13, when a polarization plate as an analyzer is arranged before the liquid

crystal light valve 7, the polarized proportion of polarized light incident on the liquid crystal light valve 7 can be further increased.

The present invention is not limited to the above embodiments, and various changes and modifications may be made without departing from the scope of the invention as defined in the claims.

As described above, according to the present invention, a polarization illumination apparatus and a projector with a small light loss can be realized. A quarter-wave optical phase plate normally has wavelength dependency. Since the vibration direction of polarized light can be changed without using the quarter-wave optical phase plate, the present invention is also effective for preventing color nonuniformity.

In the polarization illumination apparatus of the invention, the direction of polarization of the first polarized light component is changed in such a manner that the first polarized light component from the return or redirecting means is obliquely incident component from the return or redirecting means is obliquely incident on and reflected by a mirror surface of the reflection mirror. Therefore, a polarization illumination apparatus which can modulate the vibration direction of polarized light without using an optical phase plate, and has high light utilization efficiency, and a projector using the apparatus can be realized.

Claims

1. A polarization illumination apparatus comprising:

    a) a light source **(1)**;
    b) light condensing means having a reflection mirror **(2)** arranged behind said light source **(1)**;
    c) polarization beam splitting means **(20; 20, 20'; 20a, 20b; 23)** for splitting light **(1_{11})** emerging from said light condensing means into first **(1_{11S})** and second **(1_{11P})** linearly polarized light components having different directions of polarization; and
    d) redirecting means **(22)** for redirecting said first linearly polarized light component **(1_{11S})** to said light condensing means,

    characterized in that
    e) said reflection mirror **(2)** of said light condensing means has the shape of a paraboloid, and said light source **(1)** is arranged near the focal point (2c) of said paraboloid, said reflection mirror (2) being ar[illegible]

    [illegible] means (22) is obliquely incident on and reflected [illegible] the mirror surface of said reflection mirror (2), whereby the direction of polarization of said first linearly polarized light component **(1_{11S})** is changed upon reflection at said reflection mirror (2).

2. An apparatus according to claim 1,
    characterized in that
    light (1_{12}, 1_{23}) whose polarization state has been changed via said reflection mirror **(2)** propagates toward said polarization beam splitting means **(20)** again.

3. An apparatus according to claim 1,
    characterized in that
    said light source **(1)** comprises a discharge tube type light source such as a metal halide lamp or a xenon lamp.

4. An apparatus according to claim 1,
    characterized in that
    said light condensing means comprises reflection means **(2)** for redirecting light components, propagating in directions other than an incident face of said polarization beam splitting means **(20)**, of light emitted from said light source **(1)** to a portion near said light source **(1)**.

5. An apparatus according to claim 3,
    characterized in that
    said redirecting means **(22)** is arranged not to allow at least some components of the first polarized light redirected to a portion near said light source **(1)** to pass through a bulb portion of said light source **(1)**.

6. An apparatus according to claim 1,
    characterized in that
    said polarization beam splitting means comprises a plate type polarization beam splitter **(23)** constituted by a stack of a plurality of parallel plates.

7. A projector comprising a polarization illumination apparatus **(24)** according to any one of claims 1 to 6, image light forming means **(7)** for forming image light by modulating the intensity of the polarized light emerging from said polarization illumination apparatus **(24)**, and projection means **(10)** for projecting the image light formed by said light forming means **(7)**.

8. A projector according to claim 8, further comprising, in an optical path from said light source **(1)**, a color separation optical system, arranged between said polarization illumination apparatus **(24)** and said light forming means **(7)**, for separating light from said light source **(1)** into a plurality of different color light components, wherein said light forming means [illegible]

9. A projector according to claim 9, further comprising a color mixing optical system for mixing the color image light components from said plurality of liquid

crystal light valves **(7)**.

Patentansprüche

1. Vorrichtung zur Beleuchtung mit polarisiertem Licht, umfassend:

   a) eine Lichtquelle (1);
   b) Mittel zum Konzentrieren von Licht mit einem Reflexionsspiegel (2), die hinter der Lichtquelle (1) angeordnet sind;
   c) Polarisationsstrahlteilereinrichtungen (20; 20, 20'; 20a, 20b; 23) zum Teilen von Licht (1_{11}), das von den Mitteln zum Konzentrieren von Licht austritt, in erste (1_{11S}) und zweite (1_{11P}) linear polarisierte Lichtkomponenten mit verschiedenen Polarisationsrichtungen; und
   d) Umlenkeinrichtungen (22) zum Umlenken der ersten linear polarisierten Lichtkomponente (1_{11S}) zu den Mitteln zum Konzentrieren von Licht,

   dadurch gekennzeichnet, daß
   e) der Reflexionsspiegel (2) von den Mitteln zum Konzentrieren von Licht die Form eines Paraboloids hat und die Lichtquelle (1) in der Nähe des Brennpunkts (2c) des Paraboloids angeordnet ist, wobei der Reflexionsspiegel (2) so angeordnet ist, daß die erste linear polarisierte Lichtkomponente ($1_{11S'}$), die von der Umlenkeinrichtung (22) umgelenkt worden ist, schräg auf die Spiegeloberfläche des Reflexionsspiegels (2) einfällt und von diesem reflektiert wird, wodurch die Polarisationsrichtung der ersten linear polarisierten Lichtkomponente (1_{11S}) bei Reflexion an dem Reflexionsspiegel (2) verändert wird.

2. Vorrichtung nach Anspruch 1,
   dadurch gekennzeichnet, daß
   Licht (1_{12}, 1_{23}), dessen Polarisationszustand durch den Reflexionsspiegel (2) geändert worden ist, sich erneut zu den Polarisationsstrahlteilereinrichtungen (20) fortbewegt.

3. Vorrichtung nach Anspruch 1,
   dadurch gekennzeichnet, daß
   die Lichtquelle (1) eine Lichtquelle vom Entladungsröhrentyp wie beispielsweise eine Metallhalogenidlampe oder eine Xenonlampe umfaßt.

zu einem Bereich in der Nähe der Lichtquelle (1) umzulenken.

5. Vorrichtung nach Anspruch 3,
   dadurch gekennzeichnet, daß
   die Umlenkeinrichtungen (22) so angeordnet sind, daß nicht zugelassen wird, daß mindestens einige der Komponenten des ersten polarisierten Lichts, die zu einem Bereich in der Nähe der Lichtquelle (1) umgelenkt worden sind, durch einen Kolbenbereich der Lichtquelle (1) hindurchgehen.

6. Vorrichtung nach Anspruch 1,
   dadurch gekennzeichnet, daß
   die Polarisationsstrahlteilereinrichtung einen Polarisationsstrahlteiler (23) vom Plattentyp umfaßt, der durch einen Stapel aus einer Vielzahl von parallelen Platten aufgebaut ist.

7. Projektor, der eine Vorrichtung (24) zur Beleuchtung mit polarisiertem Licht nach einem der Ansprüche 1 bis 6, Abbildungslichterzeugungseinrichtungen (7) zum Erzeugen von Abbildungslicht durch Modulieren der Intensität des polarisierten Lichts, das aus der Vorrichtung (24) zur Beleuchtung mit polarisiertem Licht heraustritt, und Projektionseinrichtungen (10) zum Projizieren des durch die Lichterzeugungseinrichtungen erzeugten Abbildungslichts umfaßt.

8. Projektor nach Anspruch 7, ferner umfassend, in einem Lichtweg von der Lichtquelle (1) ein optisches Farbtrennsystem, das zwischen der Vorrichtung zur Beleuchtung mit polarisiertem Licht und der Lichterzeugungseinrichtung (7) angeordnet ist, zum Trennen von Licht von der Lichtquelle (1) in eine Vielzahl von verschiedenen Farblichtkomponenten, wobei die Lichterzeugungseinrichtung eine Vielzahl von Flüssigkristallröhren entsprechend den verschiedenen Farblichtkomponenten umfaßt.

9. Projektor nach Anspruch 8, ferner umfassend ein optisches Farbmischsystem zum Mischen der Farblichtkomponenten von der Vielzahl von Flüssigkristallichtröhren (7).

Revendications

1. Appareil d'éclairage à polarisation comprenant :

risation (20, 20', 20a, 20b; 23) divisant une lumière (1_{11}) provenant desdits moyens de condensation de lumière en des première (1_{11S}) et deuxième (1_{11P}) composantes de lumière polarisée de façon linéaire, ayant des directions differentes de polarisation;

d) des moyens de réorietation (22) réorientant ladite première composante de lumière (1_{11S}) polarisée de façon linéaire vers lesdits moyens de condensation de lumière,

caractérisés en ce que
e) ledit miroir réfléchissant (2) desdits moyens de condensation de lumière présente la forme d'une paraboloïde, et ladite source de lumière (1) est disposée à proximité du point focal (2c) de la paraboloïde, ledit miroir réfléchissant (2) étant agencé de manière que ladite première composante de lumière (1_{11S}) polarisée de façon linéaire, réorientée par lesdits moyens de réorienatation (22), arrive obliquement sur et soit réfléchie par la surface de miroir dudit miroir réfléchissant (2), de manière que la direction de polarisation de ladite première composante de lumière (1_{11S}) polarisée de façon linéaire, soit modifiée lors de la réflexion par ledit miroir réfléchissant (2).

2. Appareil selon la revendication 1,
caractérisé en ce que
la lumière (1_{12}, 1_{23}), dont l'état de polarisation a été modifiée via ledit miroir réfléchissant (2), se propage de nouveau vers lesdits moyens de division de faisceau de polarisation (20).

3. Appareil selon la revendication 1,
caractérisé en ce que
ladite source de lumière (1) comprend une source de lumière de type à tube de décharge, telle qu'une lampe à halogene-métal ou une lampe au xénon.

4. Appareil 1 selon la revendication 1,
caractérisé en ce que
ledit moyen de condensation de lumière comprend un moyen réflechissant (2), réorientant les composantes de lumière se propageant dans des directions autre qu'une face incidente desdits moyens de division de faisceau de polarisation (20), d'une lumière émise par ladite source de lumière (1) vers une partie proche de ladite source de lumière (1).

[illegible] moyen de réorientation [illegible] d'empêcher au moins certains composants de ladite première lumière polarisée réorientée vers une partie proche de ladite source de lumière (1) de passer par une partie d'ampoule de ladite source de lumière (1).

6. Appareil selon la revendication 1,
caractérisé en ce que
ledit moyen de division de faisceau de polarisation comprend un diviseur de faisceau de polarisation (23) de type à plaque, constitué par l'empilage d'une pluralité de plaques parallèles.

7. Projecteur comprenant un appareil un appareil d'éclairage à polarisation (24) selon l'une quelconque des revendications 1 à 6, un moyen de formation de lumière d'image (7) formant une lumière d'image en modulant l'intensité de la lumière polarisée provenant dudit appareil d'éclairage à polarisation (24), et un projection (10) projetant l'image de lumière formée par ledit moyen de formation de lumière (7).

8. Projecteur selon la revendication 7, comprenant en outre, dans un chemin optique partant de ladite source de lumière (1), un système optique de séparation de couleur, agencé entre ledit appareil d'éclairage à polarisation (24) et ledit moyen de formation de lumière (7), afin se séparer une lumière, provenant de ladite source de lumière (1), en une pluralité de composantes de lumière de différentes couleurs, dans lequel ledit moyen de formation de lumière comprend une pluralité de modulateurs de lumière à cristaux liquides correspondant aux composantes de lumière de différentes couleurs.

9. Projecteur selon la revendication 8, comprenant en outre un système optique de mélange de couleur, mélangeant les composants de lumière d'image en couleur provenant de ladite pluralité de modulateurs de lumière à cristaux liquides (7).

FIG. 1

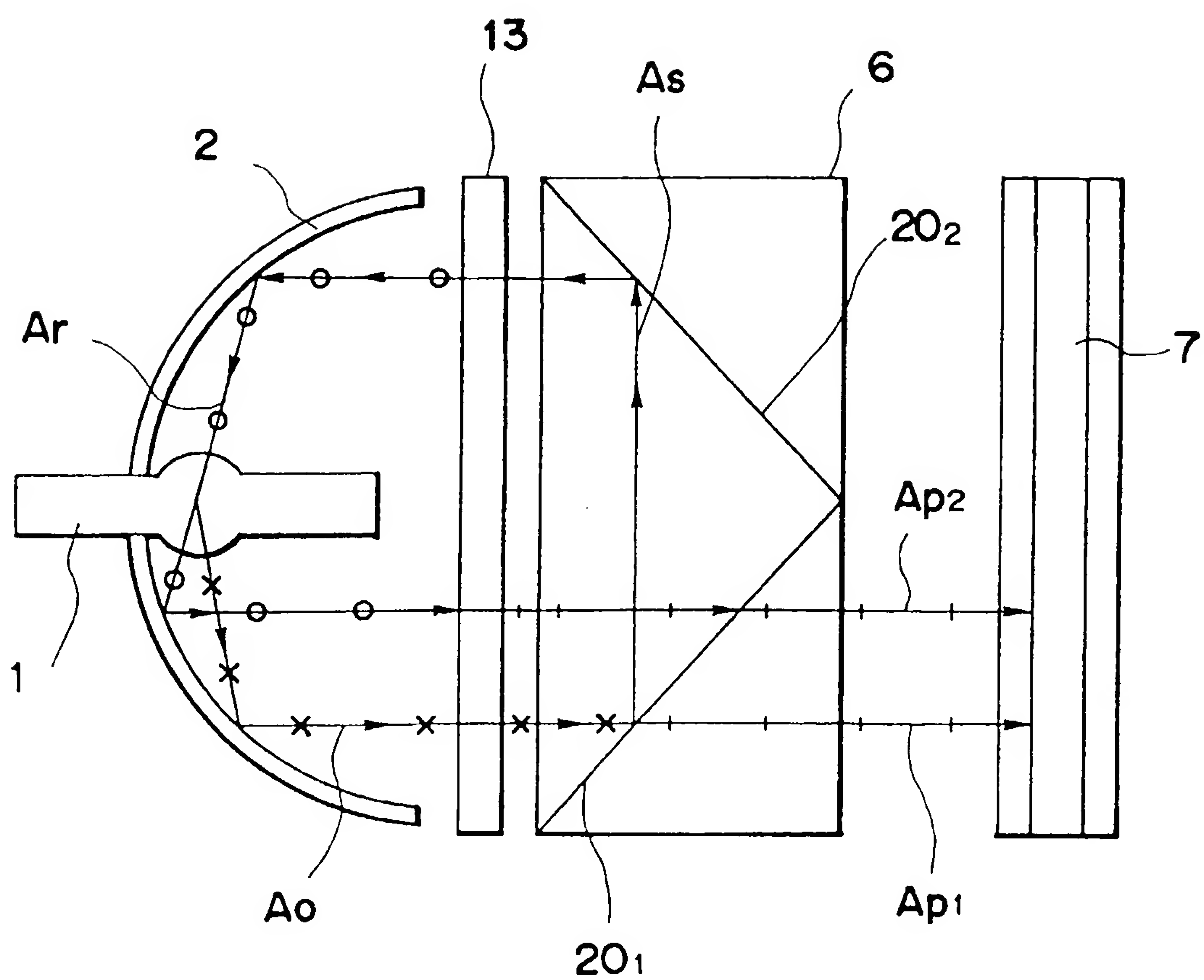

FIG. 2

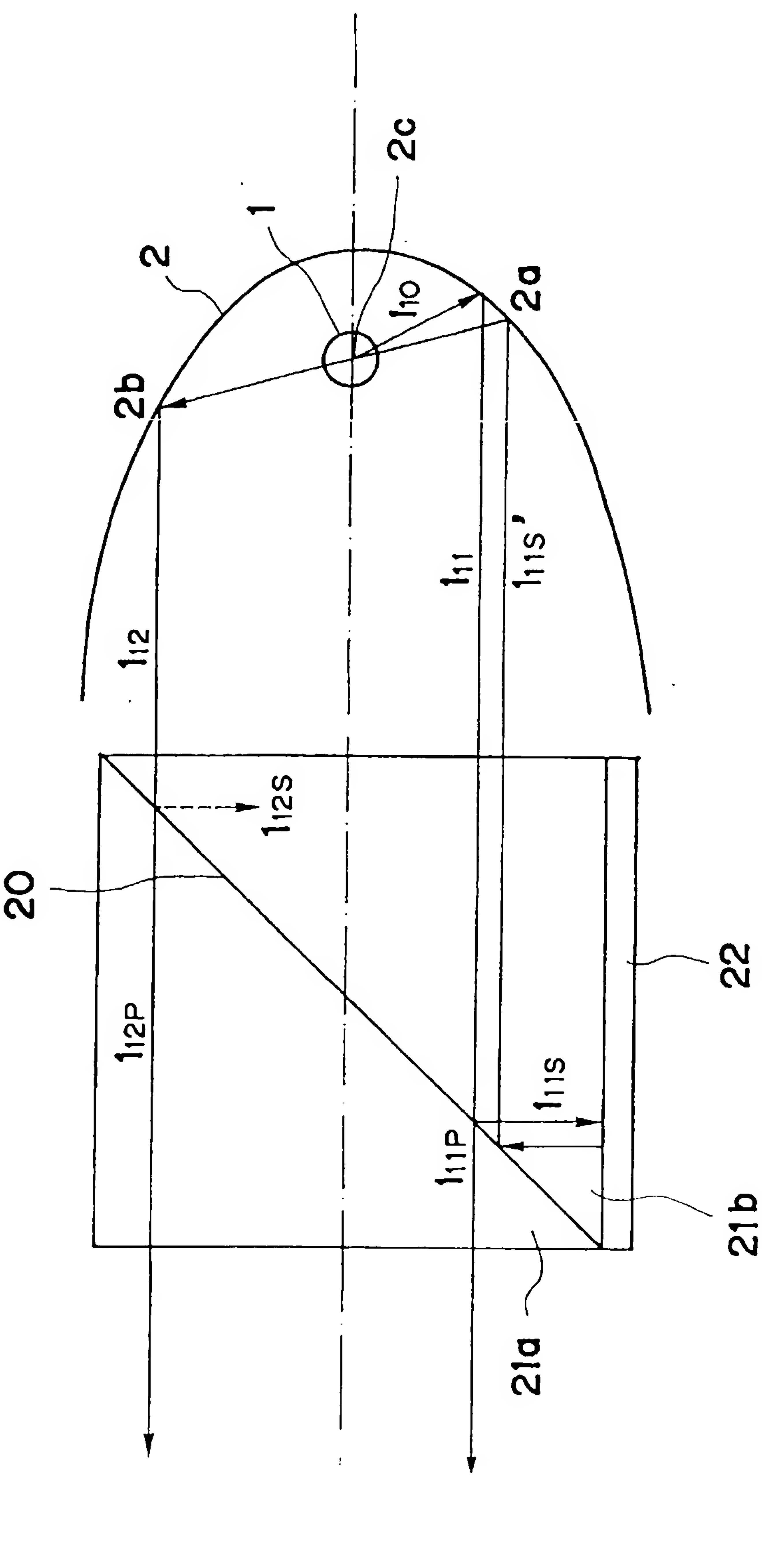

FIG. 3

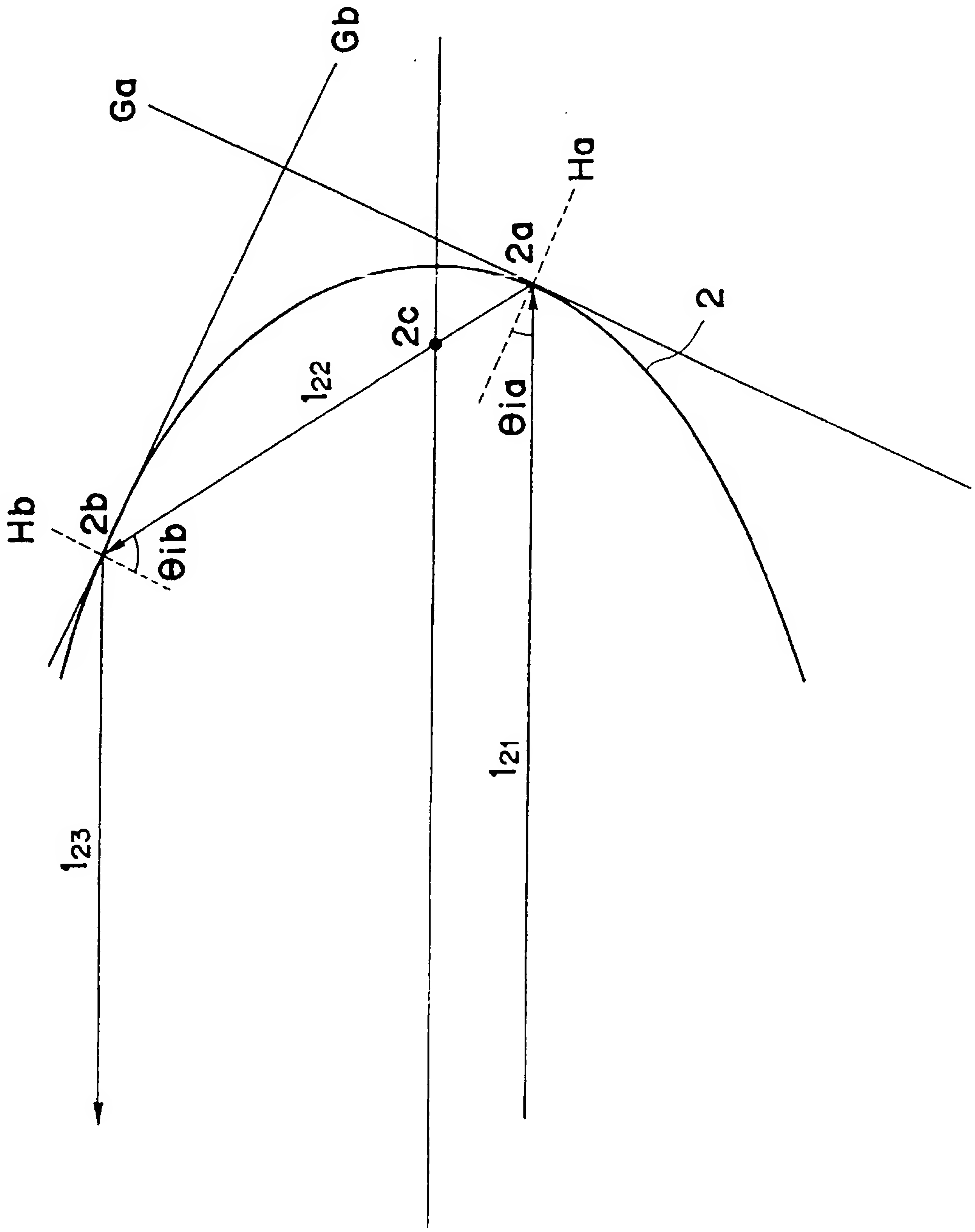

FIG. 4

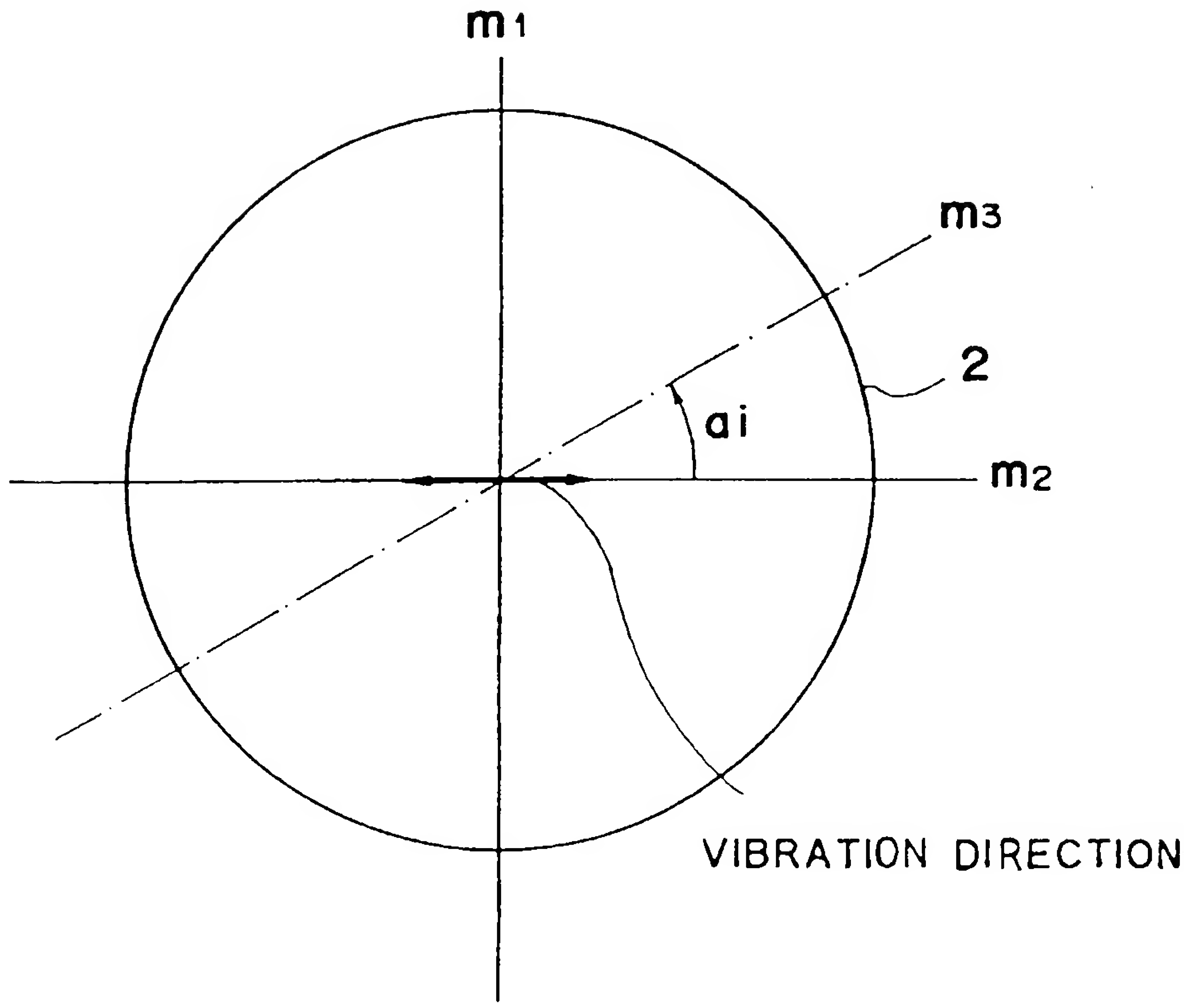

FIG. 5

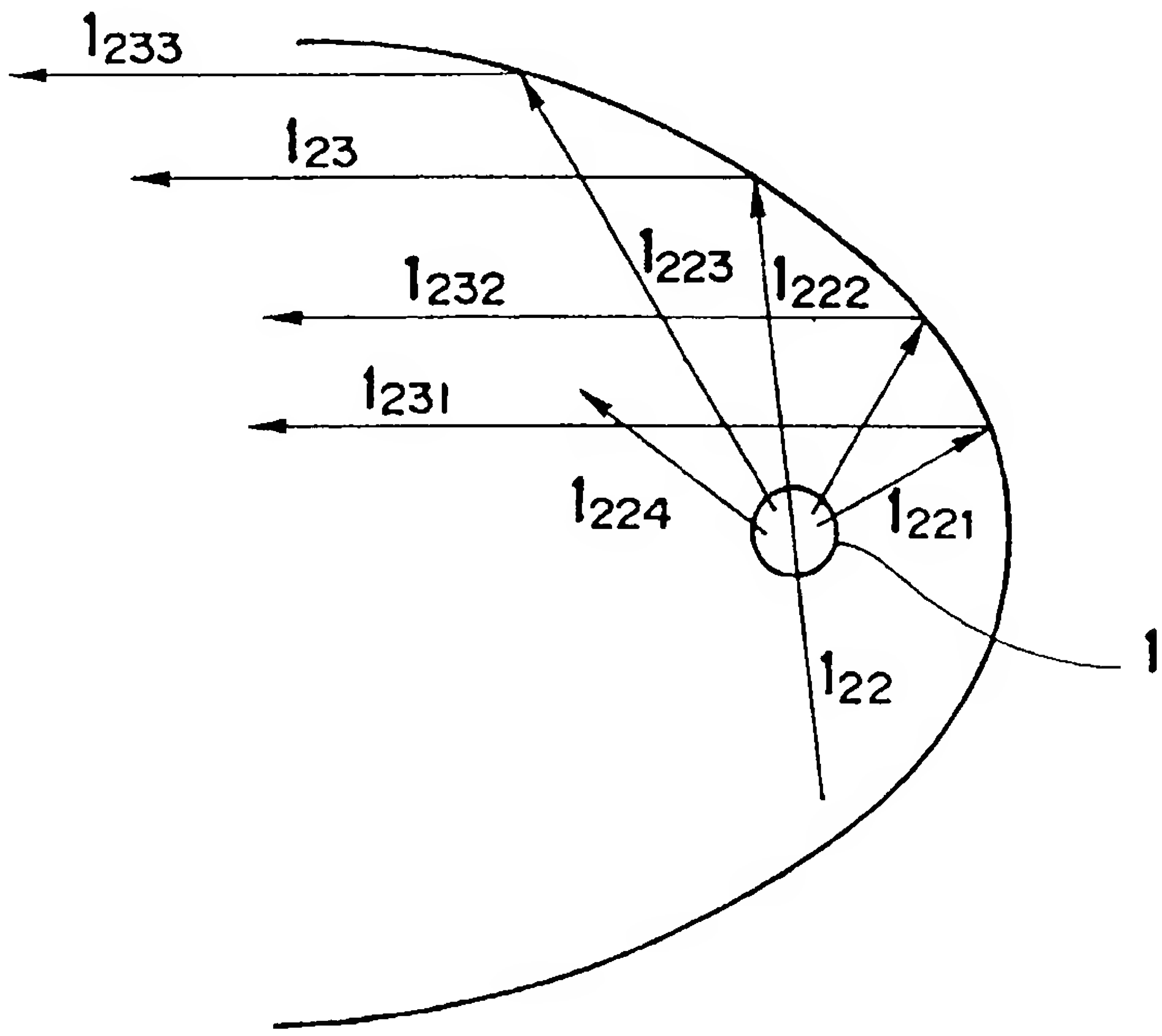

FIG. 6A

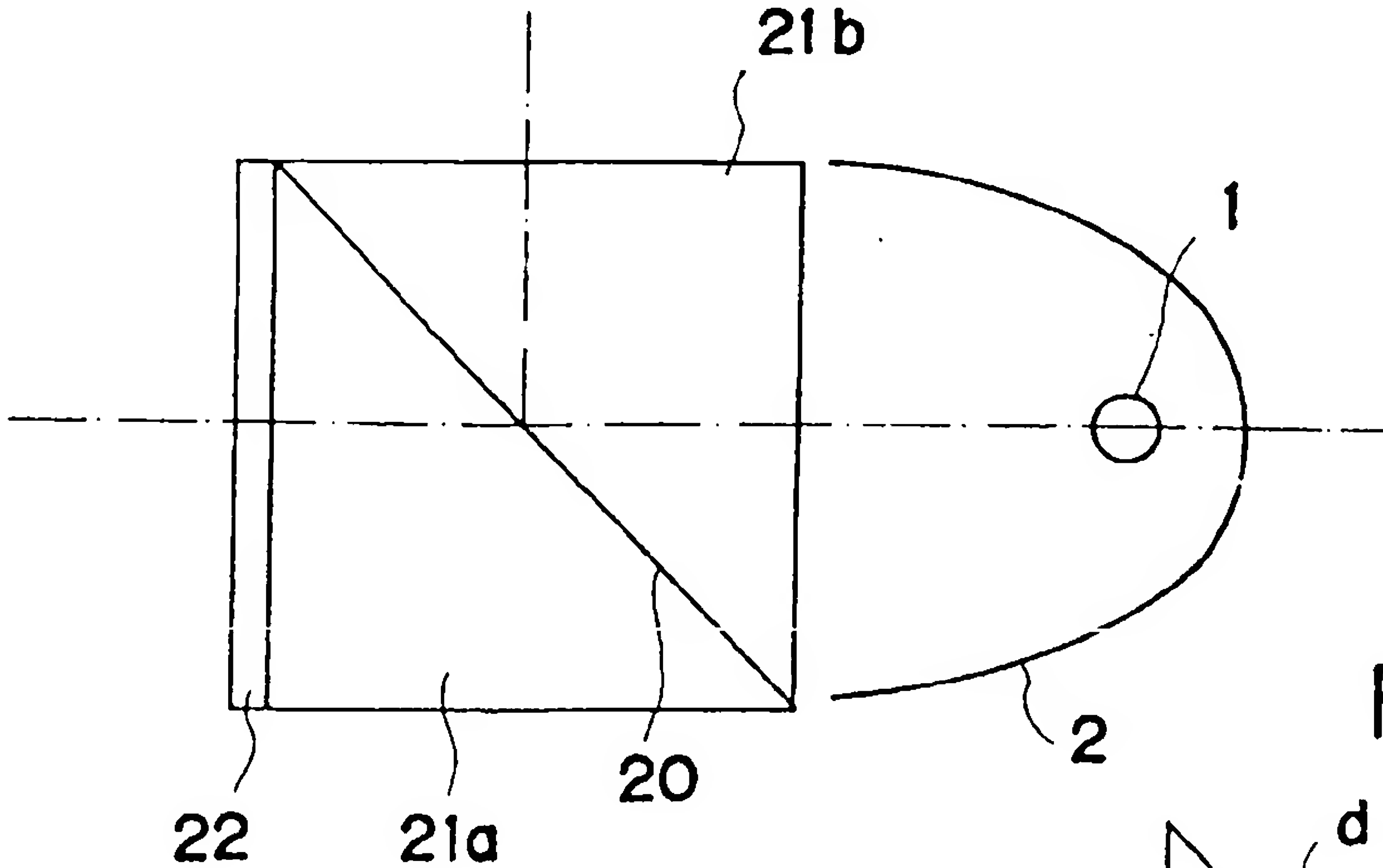

FIG. 6B

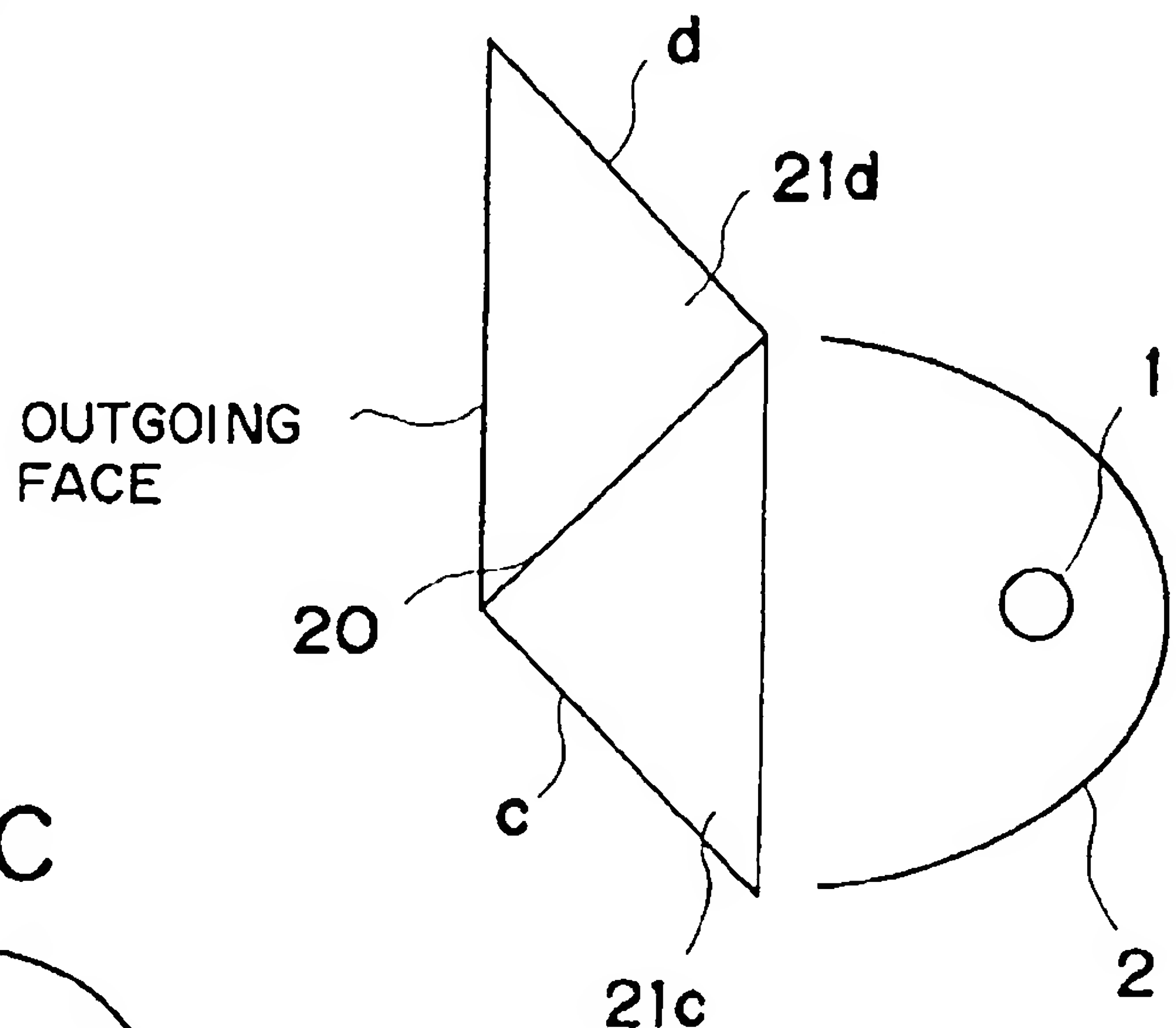

FIG. 6C

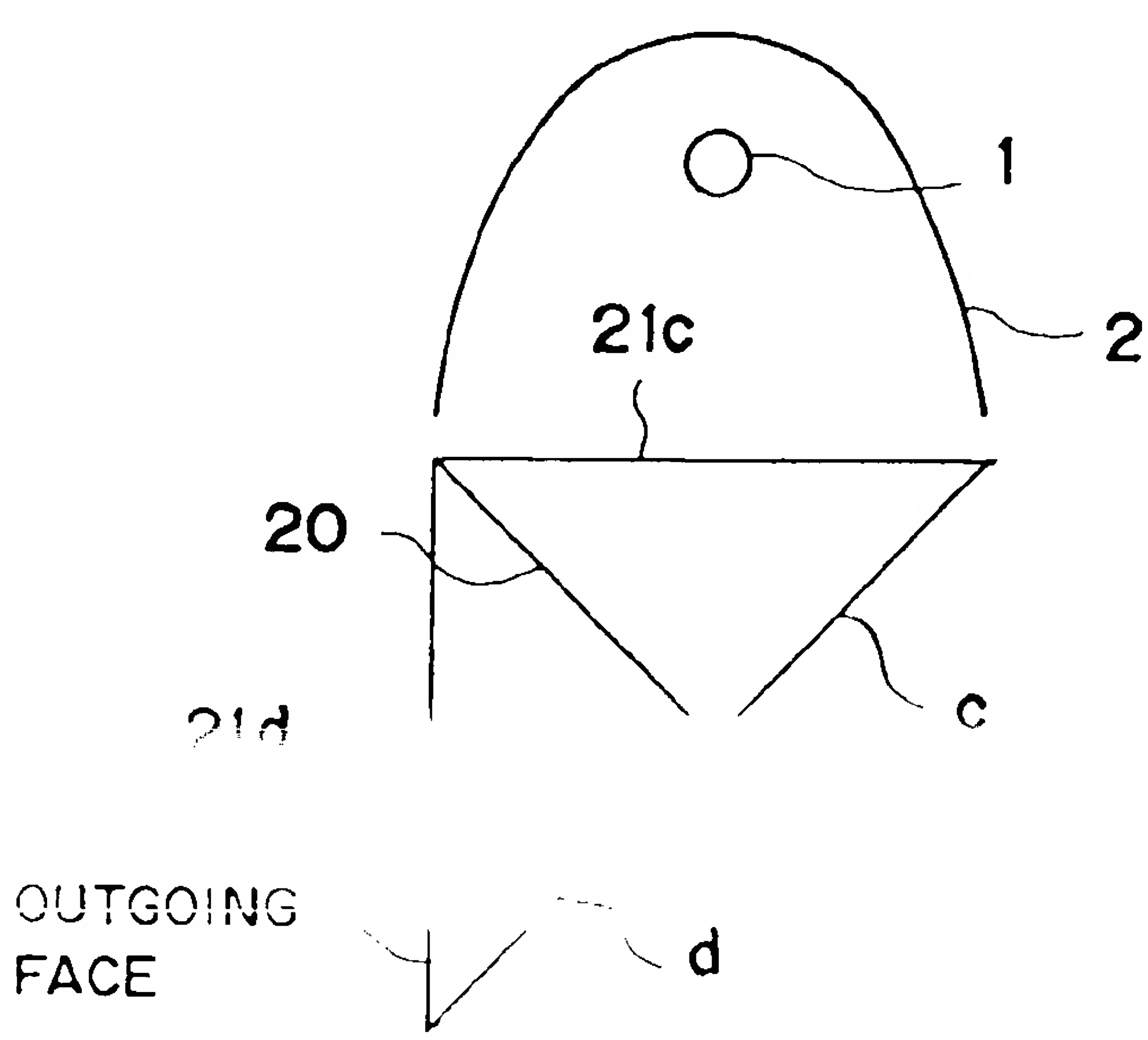

FIG. 7

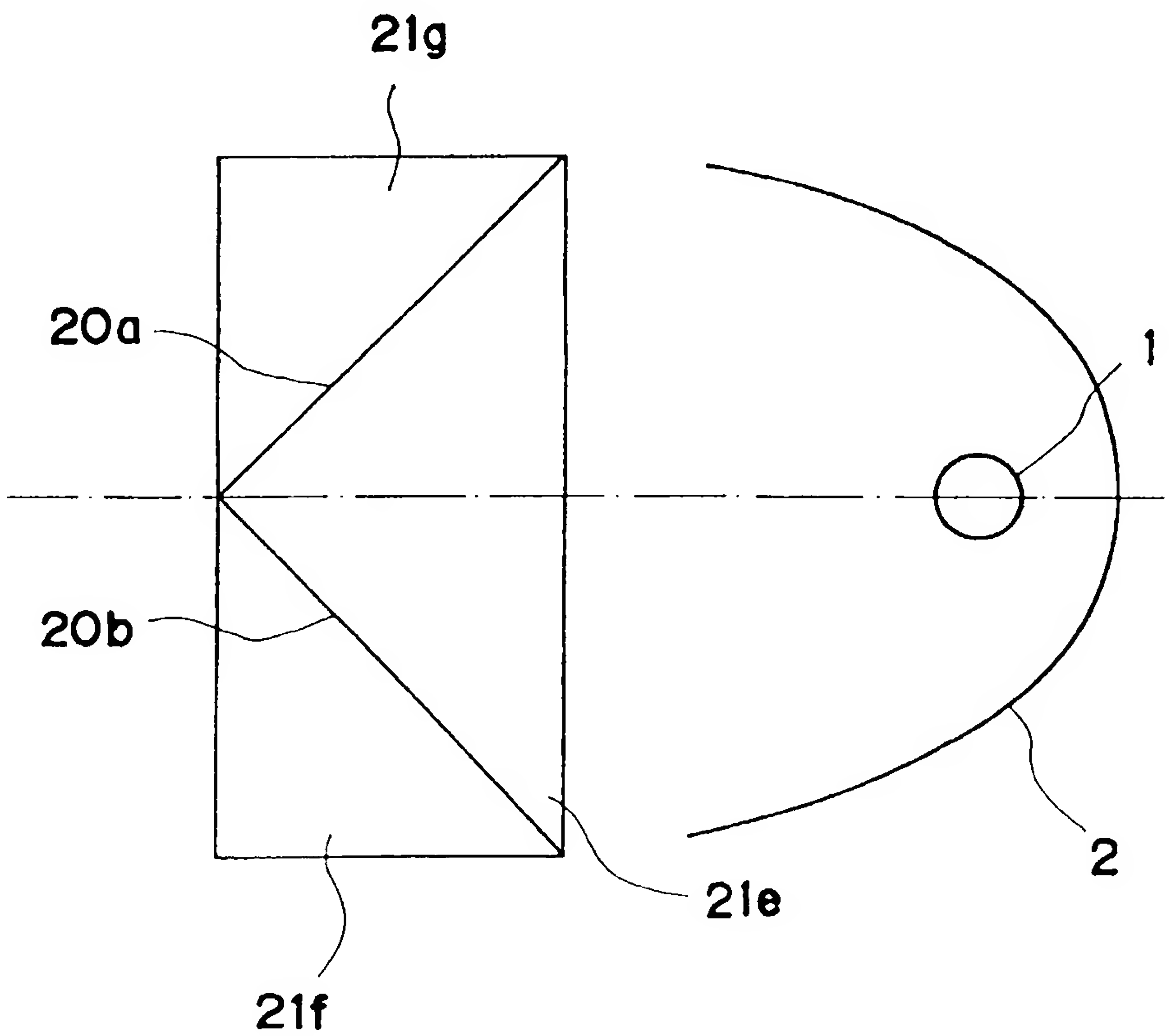

FIG. 8A

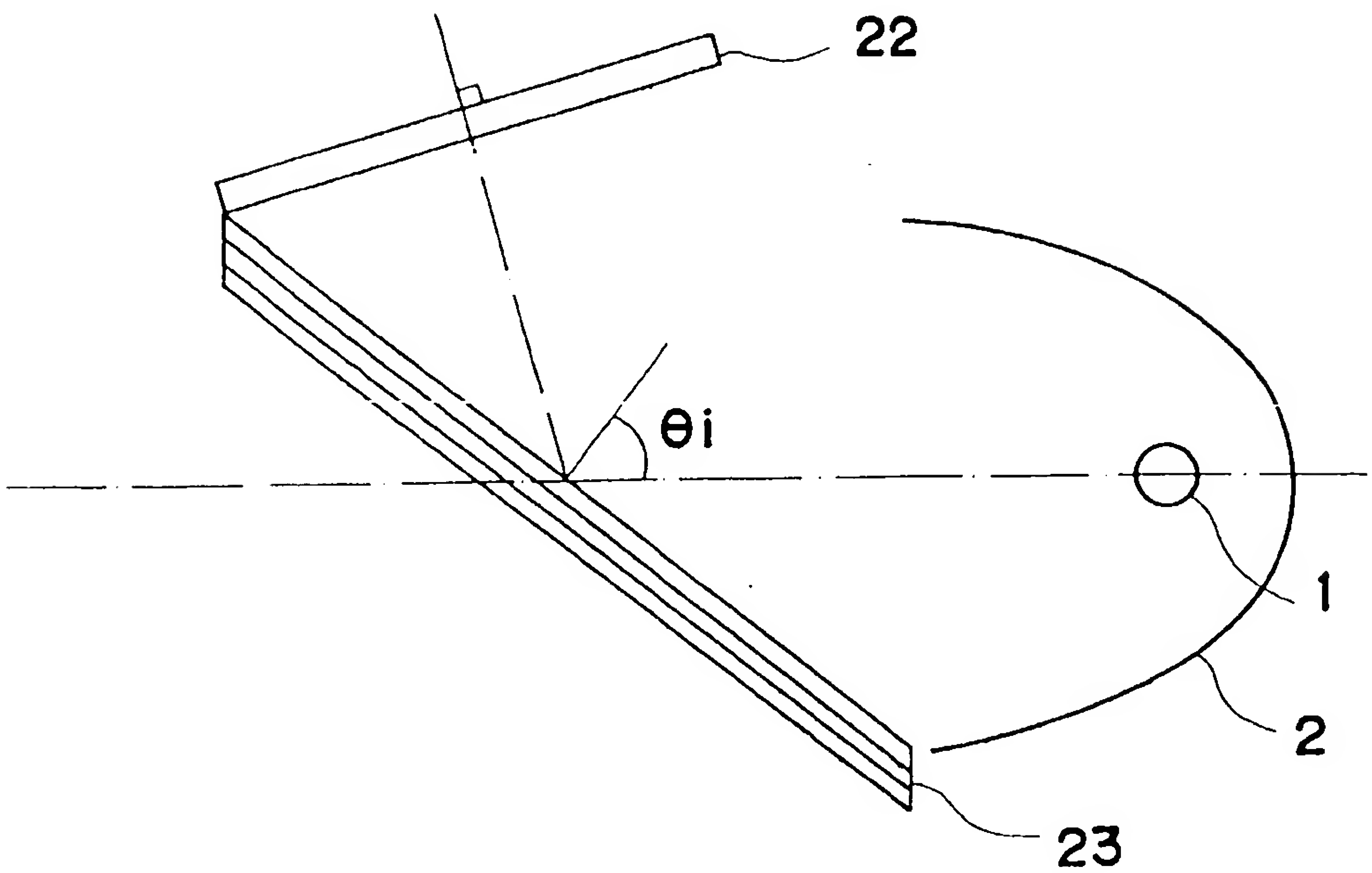

FIG. 8B

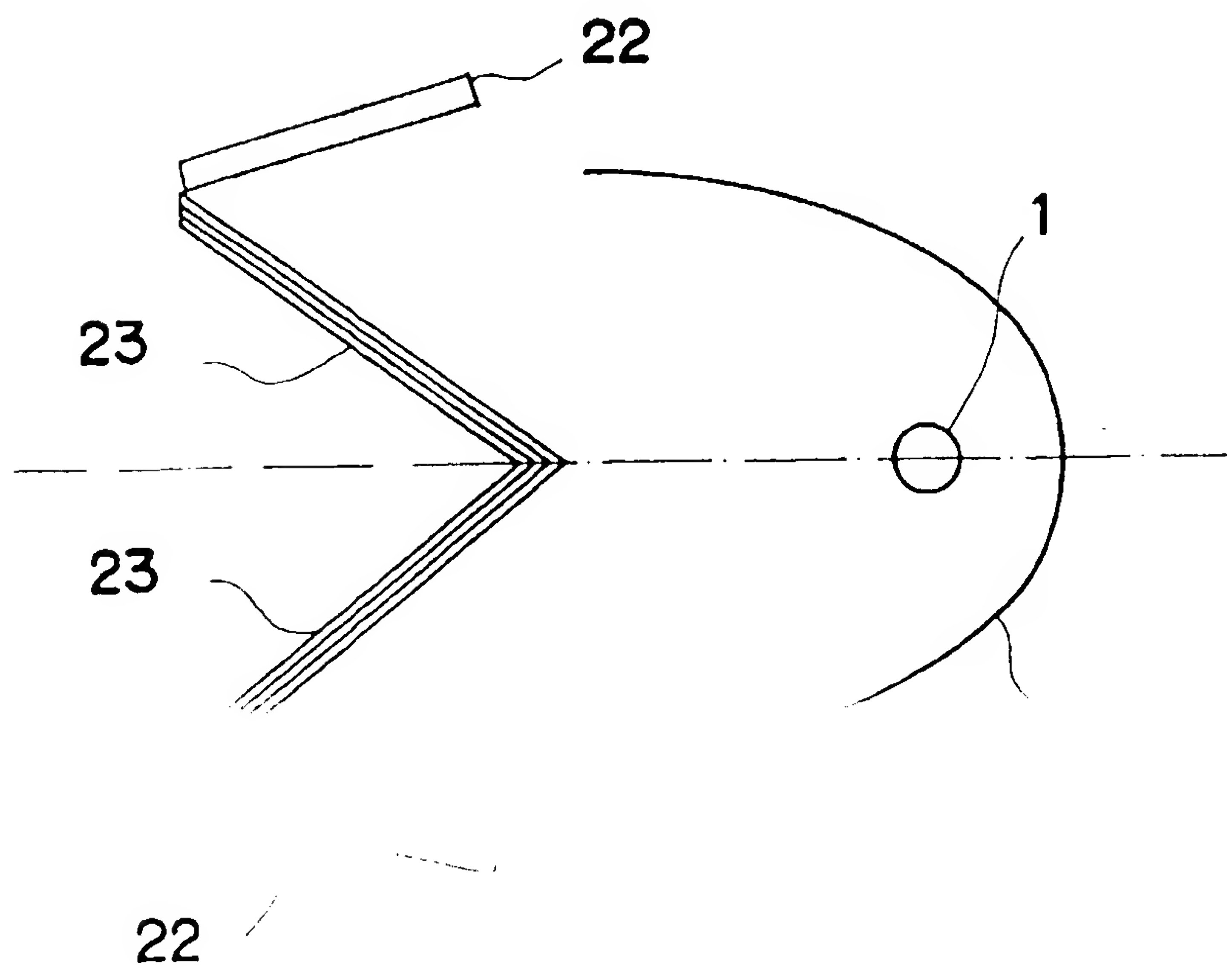

FIG. 9

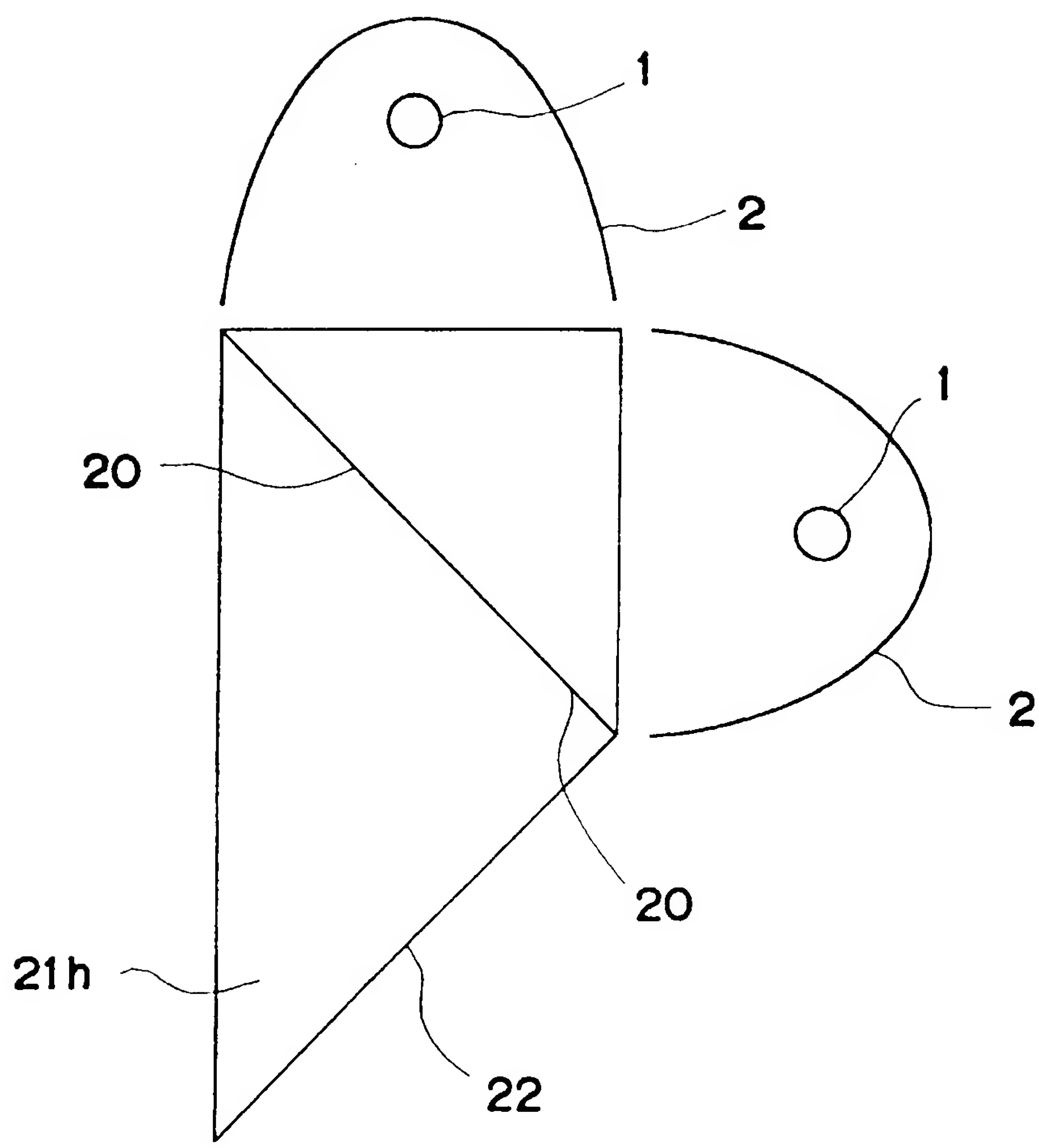

FIG. 10B

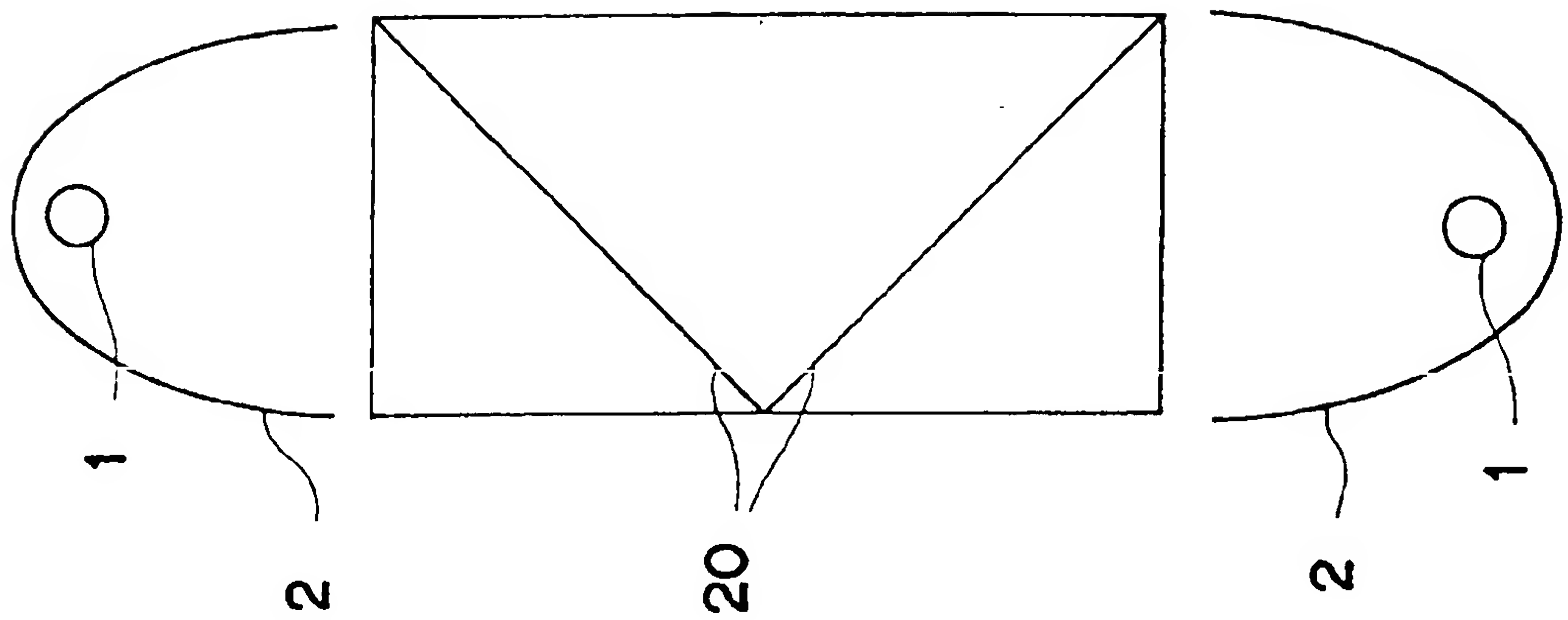

FIG. 10A

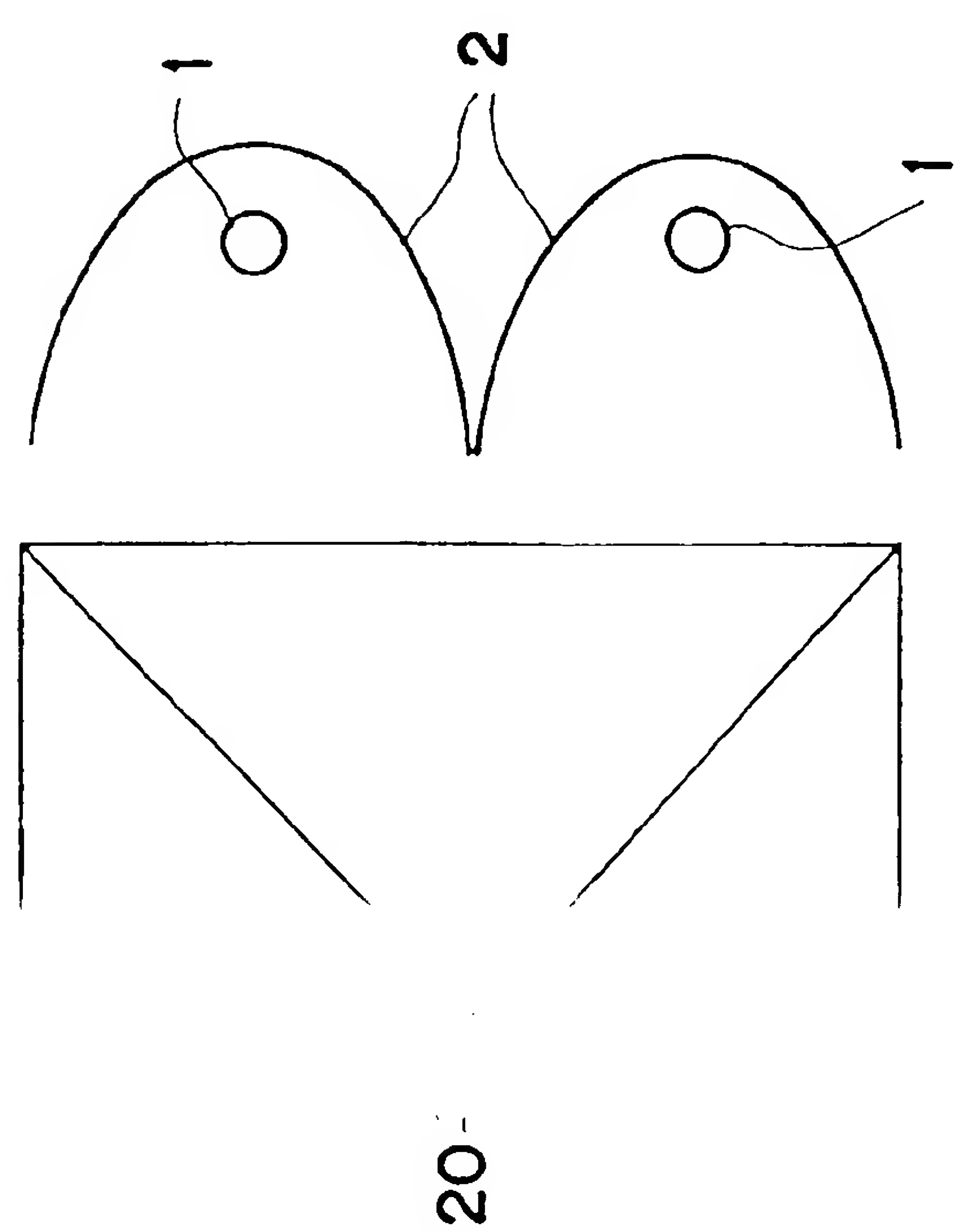

FIG. 11

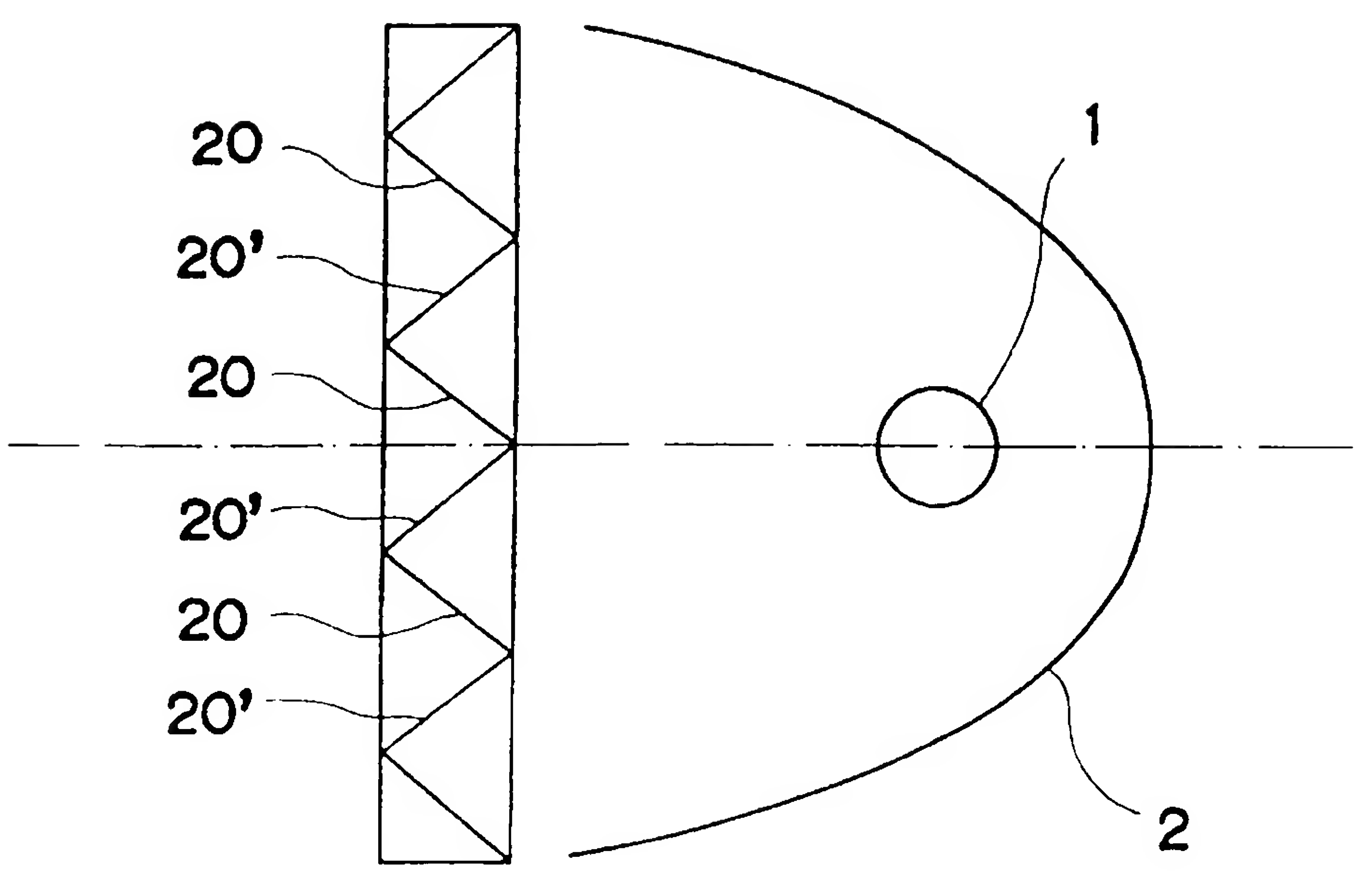

FIG. 12

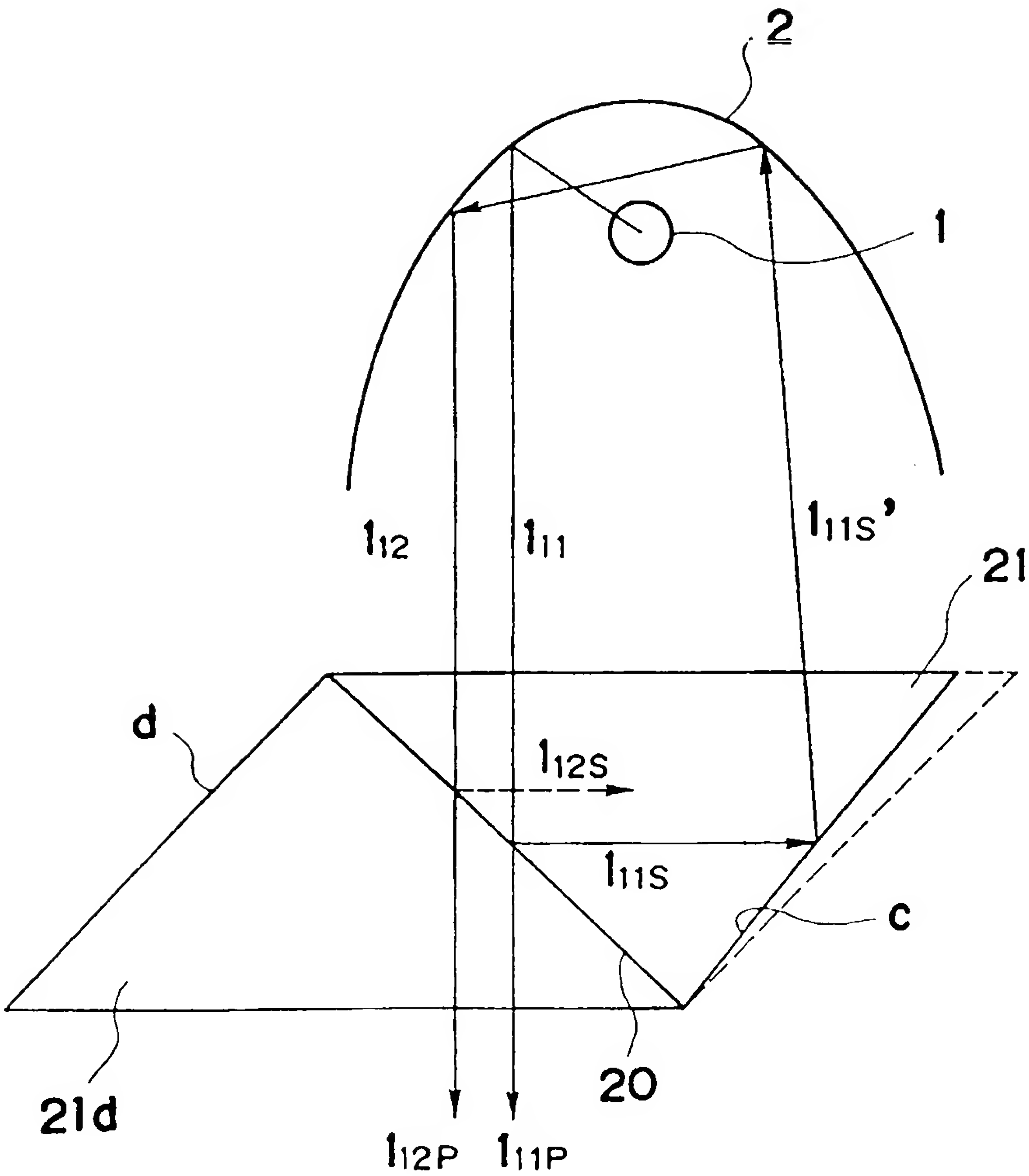

FIG. 13